9.07 IMPROVED INFRARED CLOUD ANALYSIS AND REGIONAL CLOUD PRODUCTS FROM THE CHANCES GLOBAL CLOUD DATABASE

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ABSTRACT

We are presenting the results of a new cloud detection technique using a time series of infrared and visible radiances - without any reliance on dynamic external data. From this new technique, hourly, 5-km resolution, cloud products are created over the Middle East region from the Climatological and Historical Analysis of Cloud for Environmental Simulations (CHANCES) Regional Products (-RP) database. These products are compared to Moderate Resolution Imaging Spectroradiometer (MODIS) results for the same time period. The high temporal resolution CHANCES-RP products include: frequency of occurrence of cloud, cloud/clear interval, persistence probability of clear/cloud, conditional probability of clear/cloud, as well as by-products such as visible and infrared background radiance images and persistent snow/ice maps. A new technique is presented for infrared cloud detection, using topographic elevation and land cover databases to create stratified diurnal temperature curves. These curves are compared to the actual change in infrared radiance to infer the presence or absence of cloud. [CHANCES is a global, hourly, 5-km resolution, visible and infrared cloud and radiance database formed, primarily, by merging geostationary and polar orbiting weather satellites.] This paper describes the new technique, while a companion paper by Kankiewicz et al. describes the results of the comparison with MODIS (and also CDFSII WWMCA).

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BACKGROUND

Clouds can be a show-stopper for a wide range of DoD and “intelligence” operations. Opaque clouds will prevent passive optical or infrared systems from seeing objects near the ground from an aircraft or space-based sensor. Conversely, opaque clouds will impede a ground observer who is trying to view objects in the upper atmosphere or space. Even “thin” clouds (clouds that are nearly invisible to the naked eye) can prevent important surveillance systems from “seeing” through the atmosphere.

Another application of cloud cover is in the simulation of weather impacts on current and future DoD systems. Every system that is built and deployed is first run through a series of simulators that attempt to depict the effects of the atmosphere, to include clouds, on the utility of that system. The results of such tests might indicate that a specific system will work quite well in an area that is normally void of opaque clouds, but is ineffective in a region that is predominantly cloudy. Simulators will also be given information about the diurnal cycle of clouds in a certain region, providing a sense of what time of day would be best to use a surveillance system that is hampered (or protected) by clouds.

One, often overlooked, application of cloud information is the identification of regions where the occurrence of clouds might be used to hide covert activities. Simulations of cloud cover can often provide a good indication of when and where a specific object may be hidden, or an operation might be attempted, under the cover of clouds.

Perhaps the most significant impact of clouds is in the arena of aerial or space surveillance. It should be apparent to anyone who has followed the recent activities in Iraq, that we rely heavily on our ability to collect visual and infrared images from remote platforms. Such activities can be severely limited by cloud cover. These important data are often the only source of information for tracking the movements of people or objects, or to identify changes in physical facilities at various locations. The ability to make efficient use of aircraft or satellite surveillance is essential for monitoring the locations of facilities that may be involved in the production of banned substances or devices, or buildings that house weapons or other military assets. One of the most important factors in the success of such information gathering … is cloud cover.

Under the sponsorship of the DoD Center for Geosciences / Atmospheric Research (CG/AR), CIRA has developed a series of global and regional scale cloud products that have a direct application to DoD operations, as well as the peace-time planning and simulations community.

CIRA Cloud Research …

For the past two decades, CIRA has maintained its status as one of the top centers of research in the satellite meteorology and satellite-derived global cloud products. In the past, the emphasis has been on long-term climate studies and improvements to the detection of clouds, water vapor, and precipitation from global satellite imagery. More recently, CIRA has devoted a significant effort to improving our ability to detect and forecast the occurrence of clouds in select regions of the globe where more conventional observations of cloud (ie. from surface weather observers) are not available or are not reliable.

Clouds are arguably the single most important control mechanism for atmospheric heating and cooling. They are, in effect, the thermostat that controls the amount of radiation that arrives at the earth surface (heating) or is allowed to escape to space (cooling). The impact of clouds on global warming or cooling, for example, can be many orders of magnitude greater than the impact of rising carbon dioxide levels. Unfortunately, we do not have sufficient measurements of the global distribution of clouds to assess their impact on the warming (or cooling) of the planet. It is in this light that CIRA has spent the past two decades gathering satellite data to contribute to a statistical sample of the change in global cloud cover. During this time span, CIRA has ingested and stored one of the largest collections of digital meteorological satellite data in the world.

More recently, CIRA, under the sponsorship of the CG/AR, has leveraged off of this large volume of archived satellite imagery to produce a unique set of "Regional Cloud Products". These products are providing new insights into the distribution of clouds over specific geographic regions, with unique distributions of land, water, soil types, and surface elevations. This area of research has also provided new analysis and forecasting tools for both civilian and military applications.

In this short overview – we will look at some of the potential applications of CIRA cloud research to current conflicts in Afghanistan and Iraq.

DATA AND METHOD

The data used in our recent studies are visible and infrared (11 micron) imagery from the CHANCES database. Most of the imagery over the regional product sector are from the Meteosat-5 satellite which has a sub-satellite point of 63° E. These data were assimilated into the CHANCES database format at a 1-hr and 5-km temporal and spatial resolution. A detailed description of the CHANCES data processing system and the generation of the database can be found in Vonder Haar, et al. (1995) and Reinke et al. (2000). Several key elements of cloud detection algorithm, described in these references, have been improved and are presented in the remainder of this paper.

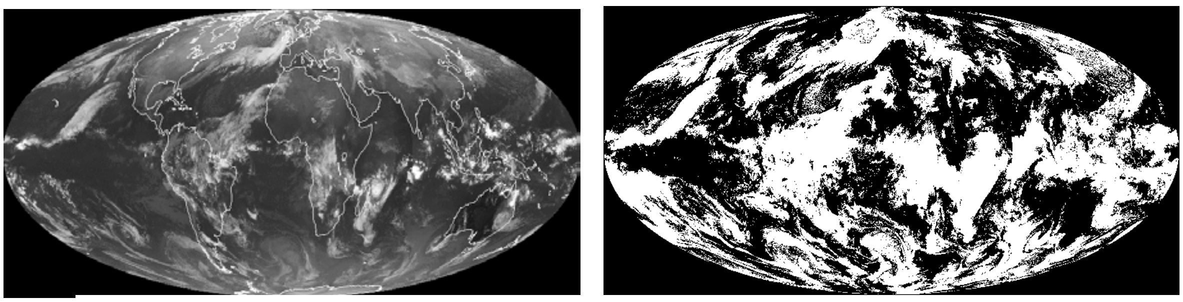


Figure 1. Example of a global CHANCES infrared radiance image (left) and the corresponding binary Cloud (white) / No Cloud (black) image.

For this "Regional Products" study, a 1024 X 1024 pixel sector (covering an area of approximately 5120 X 5120 km) over the Middle East), was extracted from the CHANCES global database. Infrared image sectors were extracted for each hour (on the hour) and visible image sectors were extracted for the hours of 0500 UTC – 1400 UTC inclusive. Examples of this geographic sector can be seen in Figures 2 and following.

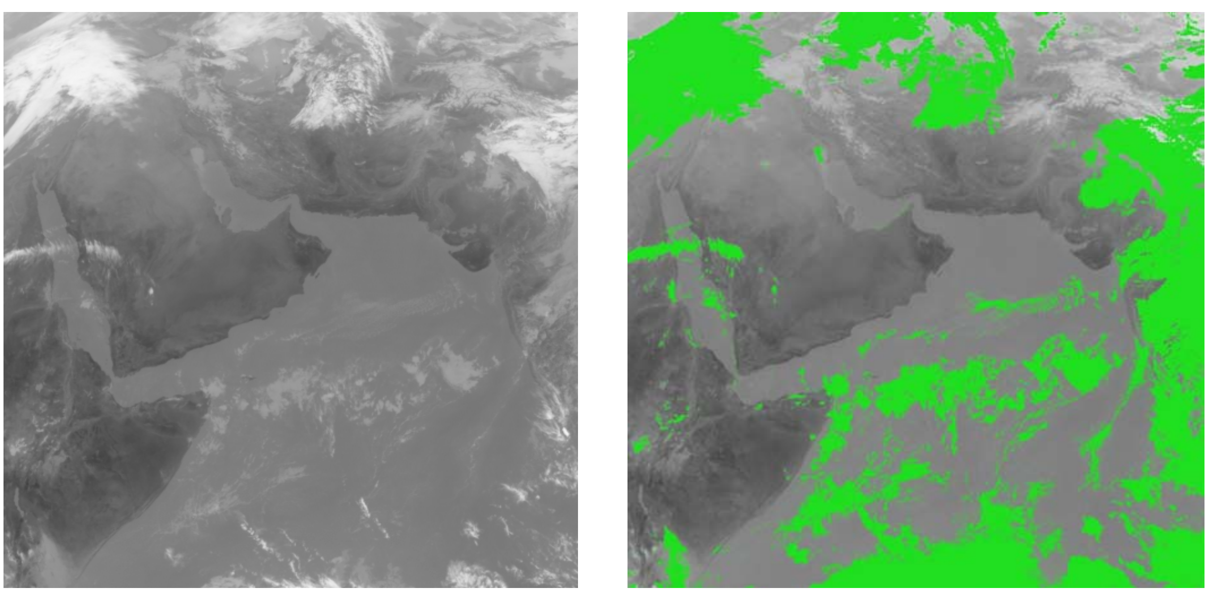
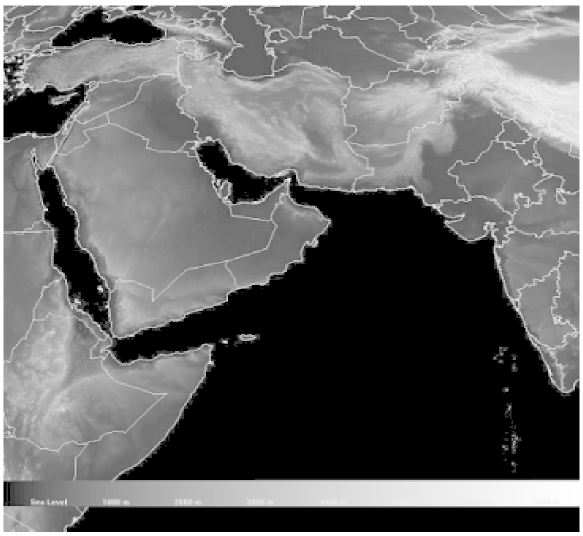


Figure 2. Example of a CHANCES Regional Products infrared image sector (left) and the corresponding binary Cloud (green) / No Cloud (black) image.

In addition, two ancillary data sets were used as input to the cloud detection algorithm. The GTOPO30 1-km resolution global elevation database was used to construct a first-guess surface temperature field and to stratify the infrared background during the "diurnal change" test. The "Global Land Cover Characteristics" database (GLCC) was used to identify land type for the purpose of assigning an expected diurnal temperature change curve. A description of GTOPO30 can be found at http://edcdaac.usgs.gov/gtopo30/README.html and the documentation for GLCC is provided at http://edcdaac.usgs.gov/glcc/globdoc2_0.html .



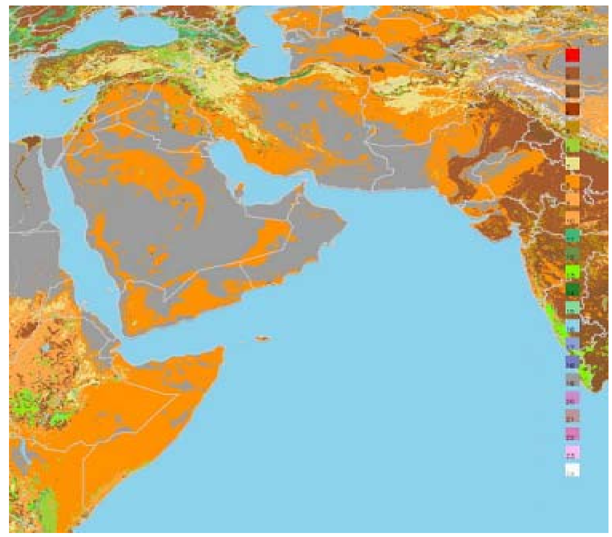


Figure 3. Ancillary data used in the CHANCES-RP cloud detection algorithm. GTOPO-30 1-km Elevation data (left) and 1-km Global Land Cover (GLCC) data (right).

Global meteorological satellite data were obtained by CIRA via both direct readout through the CIRA satellite earthstation antennae or via high-speed internet links with other world-wide earthstations. CIRA ingests, processes, and stores approximately 50GB of data per day. These data are processed to produce calibrated and quality-controlled images that are combined to produce a global mosaic of all of the available satellite data for a given hour (the basis for the CHANCES global satellite database). The region of interest is extracted from the global database. This sector is used for two applications. First, the data area used to build a "background" image that represents the scene that would be viewed under cloud-free conditions. Secondly, the images are processed to identify cloud and clear regions.

NEW IR CLOUD DETECTION METHODOLOGY

Cloud analysis for our "Regional Studies" research effort varied from the analysis used to generate cloud / no cloud products for the CHANCES database (Vonder Haar et al.1995). We will discuss the similarities and differences, and the reasons for modifying the techniques used in the global data processing system.

We start with a discussion of our infrared cloud detection method which detects clouds when the 11 micron brightness temperature is colder than an expected clear sky background. The technique is quite simple and an easy one to automate once the clear sky background is generated. The construction of this background, however, is not a trivial nor precise exercise.

The approach, that was employed in previous years of the CHANCES database, is to use a threshold above a model surface temperature field. The model that was used is the USAF Surface Temperature model (Kopp et al. 1995). The resultant database provides surface temperatures at a spatial and temporal resolution of 47 km and 3 hours. Feijt and De Valk (2001) and Feijt et al (2000) provide a good analysis of the difficulties inherent in using a surface temperature analysis from a model. Extreme care must be taken to account for diurnal cloud detection efficiency biases when using surface or numerical weather prediction estimates of surface temperature. Surface skin temperature, which creates the radiance the satellite receives, is often not the same as model surface temperature. This problem can be particularly severe under certain synoptic conditions. For instance, on a clear still night, the surface may cool much quicker than the model analysis field and at some point may be colder than the model temperature by an amount exceeding the detection threshold. Then the clear surface would be erroneously detected as cloud. Model surface temperatures may not be optimized to match satellite window channel radiances, but rather may be tuned to some other parameter irrelevant to the satellite, such as surface fluxes (Feijt et al 2000). In addition, the model fields are often at a lower resolution than the satellite data. This can lead to problems around coastlines. For instance, consider a model grid box which has a temperature representative of land (300 K). Suppose this grid box also overlaps onto a cold ocean (285 K) area which is unresolved due to model resolution. If the algorithm is using the 300 K temperature from the model as its surface temperature and views a pixel over the 285 K ocean surface, it might flag the pixel as cloudy, since it is 15 K colder than its expected value.

In this study, we use only tests and backgrounds which can be constructed from the satellite data themselves. Heritage cloud detection schemes often require spatial tests that lead to lower resolution results (Kidder and Vonder Haar, 1995). All of our tests are done at the full spatial resolution of the data. This requires excellent alignment of consecutive images, a condition which is met with the Meteosat series of satellites.

INFRARED CLOUD-FREE RADIANCE IMAGES

Cloud-free radiance images are built from the raw infrared imagery, and the GTOPO30 surface elevation database. The 1-km resolution GTOPO30 database has a vertical resolution of 1 meter and is also flagged to allow one to distinguish between land and water. These cloud-free radiance images, referred to as the "IR background", are constructed as follows:
The surface elevation data are used to construct a radiance background image that is consistent with a standard atmospheric lapse rate. The imagery is first processed to determine the mean temperature at the lowest elevation, with a separate value derived over land and water. This mean value will be composed of both clouds and water and should be biased toward the cold side, in most instances, because cloudy pixels are most often colder than the background. The obvious exceptions are very cold land in the winter months and the rare "warm cloud" caused by a sharp temperature inversion in the layer beneath the cloud. This mean value is then used as the "base" temperature for our lapse rate-based scheme. (Note: the elevation used for our 5-km resolution satellite pixels is an average of the matching 1-km resolution elevation data pixels (an image depicting the elevation data for our sector is shown in figure 3).

The available images for a given hour are then interrogated to identify the "warmest" temperature, at each pixel, during a 10-day window. (Note: The length of the window is arbitrary, and is chosen to optimize the probability of finding a cloud-free day and to minimize the impact of seasonal temperature changes or the impact of short-term surface temperature changes due to transient weather systems. The window can be longer (ie. one month) if the sector is located in the tropical latitudes.)

The brightness counts for the ten-day period, at each pixel location, are sorted and the lowest (warmest) infrared brightness count value is then used as the clear sky radiance for that pixel. This "warmest" pixel value is then compared to the value determined by the adiabatic lapse rate, in step 1, and the warmest value is used as the cloud-free radiance. (Note: Values of "0" are not used as they are assumed to be noise or missing data. In that case, the next warmest value is selected.). This method assumes that there is at least 1 day with cloud-free conditions, which is not always the case. When there is not a cloud-free day, the background will, most often, be colder than actual surface, thus the threshold test will most likely detect fewer occurrences of cloud.

VISIBLE CLOUD-FREE RADIANCE IMAGES

Visible cloud-free radiance images are built from the raw visible imagery. These cloud-free radiance images, referred to as the "visible background", are constructed as follows:
In a manner analogous to "step 2" in the infrared radiance background processing, the available visible images for a given hour are interrogated to identify the darkest radiance at each pixel pixel during the entire month. In the case of the visible data, however, the "second darkest" pixel is used rather than using an average of the coolest pixels. This is done to minimize the inclusion of pixels that are anomalously "dark" due to the presence of a shadow. The occurrence of shadows is difficult to quantify, however it has been our experience from the visual inspection of clouds (and a simple automation routine that uses the sun angle and estimated cloud height to flag a pixel as a "shadow" pixel), we have found that the occurrence of shadow is generally less than 10% of the time that a pixel is cloudy. To further minimize the impact of cloudy pixels (and random noise, which is rare but does occur) we also set a "minimum radiance" value that will not allow the visible radiance to go below an unrealistic value. A separate minimum is assigned for land and water.

INTERMEDIATE PRODUCTS USED FOR CLOUD DETECTION

Once the IR and Vis backgrounds are built, the next step is to create several intermediate products that are used in the cloud / no cloud analysis.

SNOW / ICE DETECTION

Using the hourly infrared background images, a simple algorithm identifies pixels that contain persistent snow and ice. Each infrared background pixel, over land, is interrogated to identify pixels that are "cold" and do not vary in brightness count over the 24-hour diurnal cycle. The assumption is that snow nd ice will exhibit a small diurnal change, while surrounding land pixels will show a more significant diurnal change. Figure 4 shows an example of the results of this snow detection technique.

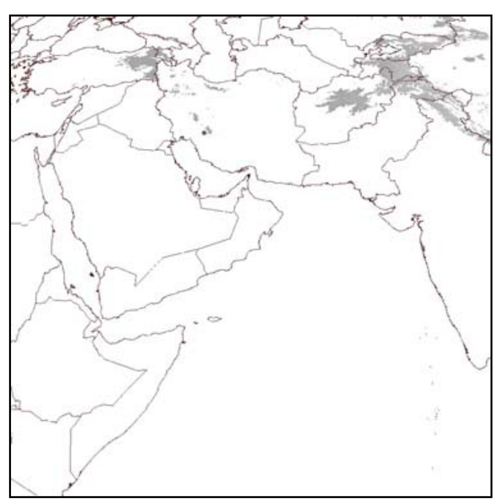


Figure 4. Example of snow/ice detection image. The area identified as snow or ice is stored as the background radiance value while all non-snow/ice points in this image are stored as a value of 255.

DIURNAL BACKGROUND TEMPERATURE CHANGE CURVES

The GTOPO30 elevation data and USGS-EROS Land Use data are used to construct diurnal temperature curves for each land use type. These curves are further stratified by elevation, in 1000 meter increments, and by hour (Note: Each 1024 pixel image represents approximately 3 time zones). Figure 5 shows an example of the curves for the land use categories that exist over the region bounded by one hour (15 degrees of longitude) and one vertical bin (0-1000 m). There are approximately 20 land types and 8 elevation bins for the regional products sector used in this study. The diurnal temperature curves for each combination of land use and elevation are used in the infrared "diurnal change" cloud test.

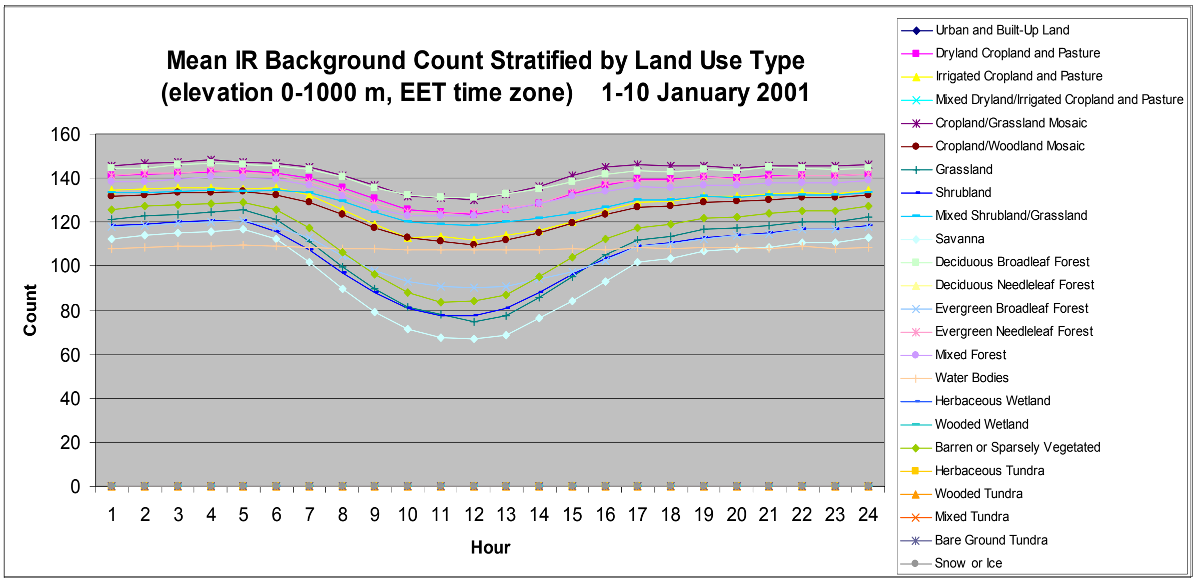


Figure 5. Diurnal curves of background radiance for one elevation bin (0-1000 m) and one time zone. Note: the "flat" curve that represents the water pixels and the large diurnal amplitude of the curve that represents the "desert" land type (blue dot).

LAND / WATER MASK AND COASTLINE CHECK

A land/water mask is constructed from the GTOPO30 database. This mask is used to identify land and water pixels for the various cloud tests. An additional test was applied to determine if a pixel was located near a coastline. A pixel was defined as a coastline point if it was land and within 2 pixels of water or vice versa. During the Threshold test, a coastline pixel was compared to the warmest background within two pixels of the point to avoid comparing cold water (or land) to the warmer land (or water) background if the image is not geographically registered with the radiance background image. Thus, coastline pixels are biased toward less cloud.

INFRARED "DIURNAL CHANGE" TEST

This test, also referred to in the literature as the "Temporal Test" (d'Entremont, 2001), uses a priori knowledge of the expected diurnal temperature change to identify cloudy pixels which do not exhibit the expected diurnal variations. Table 1 shows the decision matrix for "small" and "large" changes in the temperature value from the previous hour to the hour being interrogated. In this table, the change is identified as positive “+” (warming) or negative “-“ (cooling) and small “sm” (less than or equal to the expected diurnal change) or large “lg” (greater than twice the expected diurnal change).

diurnal change

actual change	***sm +***	***sm -***	***lg +***	***lg -***
sm +	***nc***	***nc***	***c***	***c***
sm -	***c***	***nc***	***c***	***c***
lg +	***nc***	***nc***	***nc***	***nc***
lg -	***c***	***c***	***c***	***nc***

C = Cloud   NC = No Cloud

Table 1. Diurnal Change decision matrix

The test proceeds as follows: Each pixel is identified by land type and elevation. The expected diurnal change for that land type and elevation is compared to the actual change from the previous hour and the decision matrix is used to tag the pixel as cloudy, clear, or no change.

THRESHOLD TEST

Each visible and infrared image pixel is then compared to its respective background image for that hour. If an image pixel is colder (infrared) or brighter (visible) than the corresponding pixel on the respective cloud-free background (plus a threshold value), the pixel is considered to be cloudy. A threshold is used to minimize false alarms and account for changes in background temperature over the month of images (figure 6).

Figure 6. Infrared Threshold test. The infrared background for the hour that is being processed (center) is subtracted from the image that is being processed. All pixels that exceed the background by a threshold amount are tagged as “cloudy” (green on right).

The thresholds are determined empirically by varying the threshold over land and water and examining the results. A study was done to determine the sensitivity of the cloud amount to variations in threshold (figure 7). Initial thresholds were chosen to minimize the "error" due to selecting a threshold that is too large or too small.

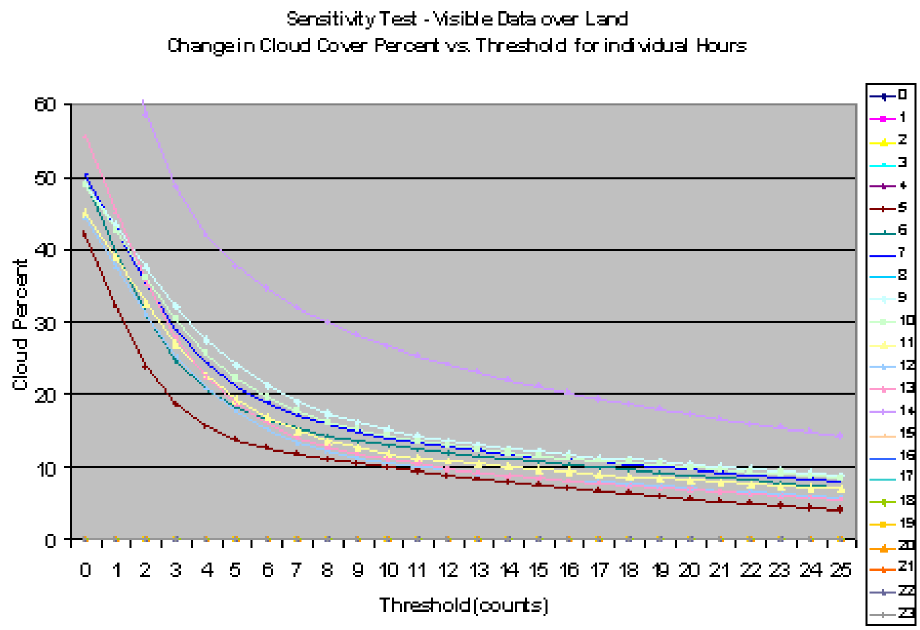


Figure 7. Example of sensitivity test for the visible threshold over land. A threshold change from 20 to 19 will produce approximately 1% more cloud. In contrast, a change from 3 to 2 will produce approximately 10% more cloud. In this study, we use a visible threshold of 9 which is below the maximum rate of influence of threshold selection on cloud detection amount.

A sensitivity test was run on both the visible and infrared thresholds and over land and water for both.

DETECTION OVER SNOW AND ICE

If the background pixel is identified as snow or ice, no threshold test is applied to the visible data. In the case of infrared data, a smaller threshold is used. The value of that threshold is adjustable, but normally tied to the brightness count value of the infrared background, so the threshold decreases as the background (snow/ice) temperature decreases. This is based on the assumption that the very cold snow fields will most likely be homogeneous and exhibit a constant radiative temperature. Thus, even a slightly cooler value on the actual imagery would indicate a colder, and thus cloudy, pixel.

LATITUDINAL BIAS OF WATER THRESHOLD (INFRARED)

For this image sector, a smaller infrared threshold is used over colder water. This is implemented by applying a latitudinal variation to the threshold, based on the mean temperature of the water bodies in the sector that is being processed. This is done by manually interrogating water pixels to determine the optimal threshold for the detection of cloud, without over-detecting in the higher (and normally colder) latitudes. This variation made a significant decrease in the over-detection of cloud over cold water bodies and will be studied further to make it general enough to use on the global cloud detection model.

DATABASE STRUCTURE

The results of all tests, along with flags for land/water, day/night, and sunglint are stored in the CHANCES-RP database as a 16-bit packed integer for each pixel location. Figure 8 shows the database format and figure 9 is a graphic display of the image for a given image time.

Byte 1

Bit #	0	1	2	3	4	5	6	7
bit value	1	2	4	8	16	32	64	128
Contents	SATID	SATID	SATID	SATID	VIS DATA USED	VIS CNC	"ORIG" IR CNC	"NEW" IR CNC
	LSB							MSB

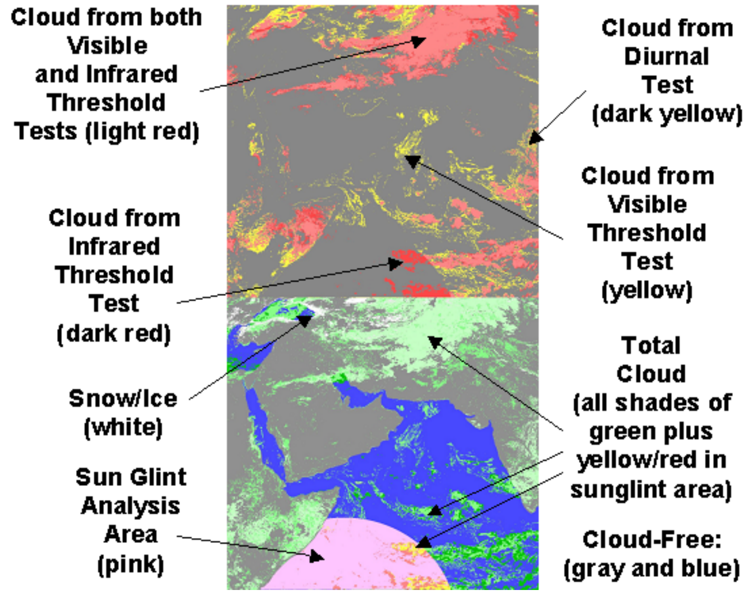
Byte 2

Bit #	0	1	2	3	4	5	6	7
bit value	1	2	4	8	16	32	64	128
Contents	DIURNAL TEST	DIURNAL CNC	OPEN	DAY / NIGHT	GLINT	"COMB" CNC	SNOW / ICE	LAND / WATER
	LSB							MSB

Figure 8. CHANCES-RP database format. The “original” infrared Cloud/No Cloud value is the one determined by the CHANCES global cloud detection technique and the “New” is the cloud / no cloud as determined by the improved technique described in this paper.

The database consists of a 4-bit satellite id and 12 single-bit data flags. A flag is set when visible data are available and when various tests are performed. Individual flags are also set when cloud is detected by the various tests, with separate cloud flags for visible and infrared threshold tests, and the ir diurnal change test. Separate flags are set to indicate if the point is over land, if the point is in the sunglint region, if the point is flagged as snow/ice covered, and if the point is in the daytime sector. The “original” ir cloud flag is set based on the CHANCES global algorithm and the “new” ir cloud flag is set based on the improved ir algorithm described in this paper.

Figure 9. A graphical display of the database flags for a single image time is shown to the right. The upper half is data byte 1 and the lower half is byte 2 (as detailed in figure 8).



REGIONAL PRODUCT EXAMPLES

After cloud detection was completed, several cloud-related products were produced. Examples of some of the products produced to date include:

1. FREQUENCY OF OCCURRENCE OF CLOUD AND PDF OF FREQUENCIES

A frequency of occurrence image was built for a given hour of the month by simply constructing the percentage of time that each pixel was cloudy for that hour. Figure 10 shows an example of a Frequency of Occurrence image for January 2001 and the PDF for that month.

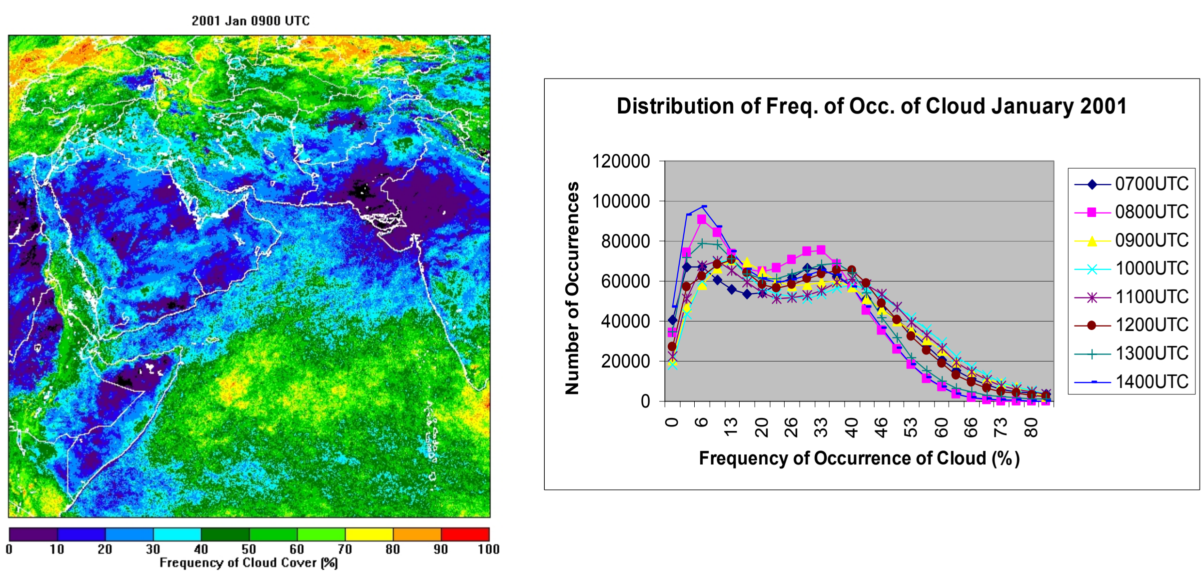


Figure 10. Example of a frequency of occurrence of cloud image (January 2001, 0900 UTC) and the PDF for a range of hours during that month.

2. CLOUD/CLEAR INTERVAL

This product is produced by constructing a table that shows the number of occurrences of cloudy or clear intervals for a range of interval distances. Figure 11 (left) shows an example of this product.

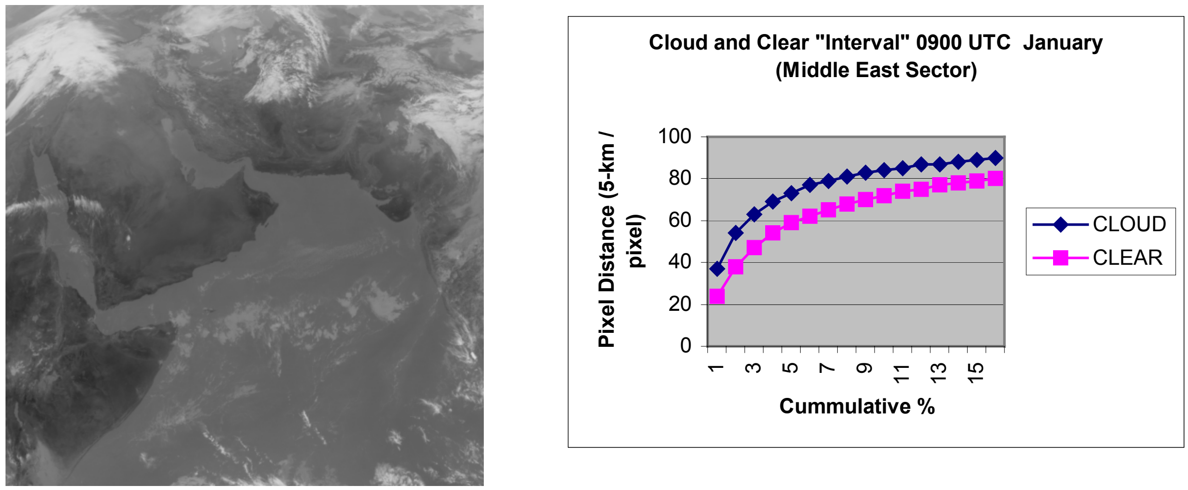


Figure 11. Example of a cloud (clear) interval plot for the image on the left. From the plot one can conclude that approximately 5% of the cloud elements detected in this image are less than 60 pixels (300 km) in horizontal extent (average of length and width) which would lead to a conclusion that most of the cloud detected is extensive bands of cirrus (including thin cirrus) or interconnected low and high cloud – as opposed to smaller cumulus cells. (This same product, produced over Florida in another study, showed a cloud interval of less than 10 km for the 5% frequency bin.).

3. CONDITIONAL CLIMATOLOGIES

This product is produced by determining the probability of a pixel being cloudy at a subsequent hour if it is cloudy/clear at the present hour. An example of this product is shown in Figure 12 (left).

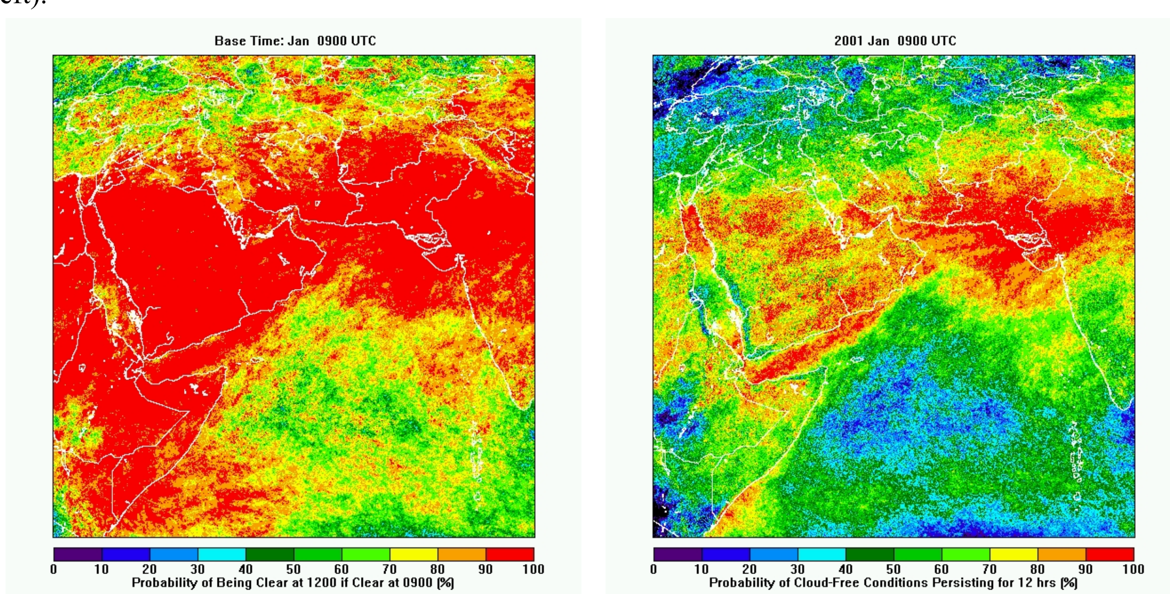


Figure 12. Example of a Conditional Climatology (left) showing the probability of being clear at 1200 UTC if initially clear at 0900 UTC (taken from January 2001 data). Also shown is a Persistence Probability image (right) showing the probability of cloud-free conditions persisting for 12 hours if a given location is cloud-free at 0600 UTC.

4. **PERSISTENCE PROBABILITIES**

Figure 12 (right) shows an example of a Conditional Probability product. This product gives the probability that a cloudy or clear pixel will persist for a given period of time.

COMPARISON WITH MODIS

Validation of satellite-based cloud detection techniques is difficult because there is little "ground truth" to serve as the basis for comparison. Surface observations are a very sparse data set and incongruities between satellite and surface observations make the comparisons meaningless in most instances (This is due, simply, to the fact that satellites are viewing cloud tops and surface observers are viewing cloud bases).

For this study, we used the MODIS cloud analysis as our standard. We assumed that the multi-channel MODIS algorithm would provide us with the best cloud analysis available, at or below the resolution of the CHANCES-RP product. A companion paper in these proceedings, by Kankiewicz et al., provides details of cloud detection results from MODIS, CHANCES-RP, and CDFS II (WWMCA). Figure 13 shows the frequency of occurrence of cloud during "nighttime hours", from the CHANCES-RP and MODIS cloud analyses, for a 40-day period (March 8^{th} – April 17^{th}, 2003), during Operation Enduring Freedom. The CHANCES-RP thresholds were adjusted to produce an analysis that matched that from MODIS.

CHANCES-RP **MODIS**

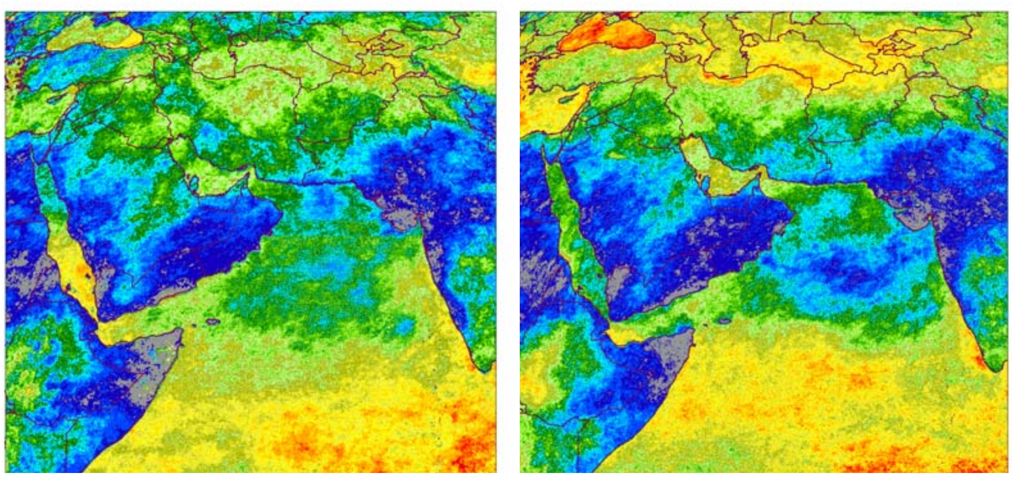


Figure 13. Frequency of occurrence of cloud (%) during "nighttime" hours for a forty-day period (8 March through 17 April 2003). The image on the left was built from CHANCES-RP and the image on the right from the MODIS cloud product.

The objective in the study was to identify biases in the CHANCES-RP analysis through a comparison with the MODIS cloud product. Shortly after the study began, we also were given access to CDFS II WWMCA cloud analysis products for the same period and included those data in the study. The overriding purpose of the study was to determine if the 2-channel CHANCES-RP cloud analysis could be tuned to match MODIS and subsequently used to produce accurate hourly, 5-km resolution, cloud/no cloud products over the entire global geostationary meteorological satellite footprint. As one can see from figure 13 (and other results shown in Kankiewicz et al.), the results are very promising.

SUMMARY

Recent studies of an improved cloud detection algorithm have shown a significant improvement in the placement and amount of cloud detected. A companion study (see Kankiewicz et al. in this same proceedings) shows the results of a comparison of the CHANCES-RP improved cloud detection technique with cloud analyses done by MODIS and the USAF CDFS II WWMCA. The study identifies biases, similarities, and differences between all three techniques. The authors believe that, with the proper selection of thresholds and the use of the improved diurnal and background threshold tests, two-channel geostationary data can produce a cloud detection that is very close to the results of the improved multi-channel MODIS product.

Figure 14 sums up one of the more significant reasons for our pursuit of a better cloud detection technique. Traditional cloud products, based on climatologies derived from surface observations, are missing a significant portion of the world's cloud cover. Our objective is to show that a relatively simple 2-channel CHANCES-RP cloud analysis can be used to produce a reliable, hourly, 5-km resolution, cloud/no cloud analysis over the entire global geostationary meteorological satellite footprint.

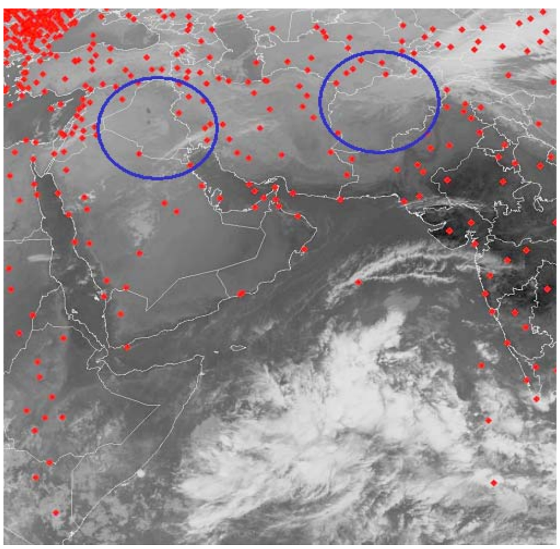


Figure 14. Typical coverage of surface reporting stations for a synoptic (3-hrly) reporting cycle. Note the lack of observations over Iraq and Afghanistan.

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